Chapter 6
Review
New Aspects in Tropical Silviculture

Michael Weber

Abstract During recent decades many environmental, social and legal conditions for sustainable management of forest resources have changed. Against this background, traditional and well-established silvicultural practices have to be reevaluated concerning their impact on conservation, biodiversity and environmental services and functions but also concerning their capability to ensure the ability of forest ecosystems to adapt to global environmental changes and to deliver the products and services that are requested by society. This chapter reviews exemplarily some of these new aspects, such as climate change, increased importance of goods and services other than timber and increased requirements for inventory, monitoring and planning as well as the consequences for silvicultural science and practice.

Keywords Climate mitigation · Adaptation · Biodiversity · Conservation · Nonwood forest products · Ecosystem services · Inventory

6.1 Introduction

For many decades the provision of pragmatic procedures to sustain a steady yield of wood from a few economically attractive species has been considered the main objective of tropical silviculture (Bertault et al. 1995). Accordingly, earlier books about silviculture in the tropics dealt mainly with traditional silvicultural systems in different regions and types of forests (e.g., Bruenig 1996; Dawkins and Philips 1998; Lamprecht 1986). In recent years, forest management and silviculture have faced substantial shifts in the conditions and requirements for sustainable use of

M. Weber
Institute of Silviculture, Center of Life and Food Sciences Weihenstephan, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany
e-mail: m.weber@forst.wzw.tum.de

S. Günter et al. (eds.), *Silviculture in the Tropics*, Tropical Forestry 8,
DOI 10.1007/978-3-642-19986-8_6,

forest resources, mainly owing to changes in societal and environmental circumstances on global and regional levels. A few of them should be mentioned here:

- Since the world population reached six billion in 1999, it has continued to grow by 83 million per year and will reach seven billion in 2011 (PRB 2009).
- The global forest area experienced a net loss of 5.2 million hectares per year in the period from 2000 to 2010, primary forests have been reduced by 40 million hectares since 2000 and the area designated primarily for productive purposes has decreased by 50 million hectares since 1990 (FAO 2010).
- Between 1995–1997 and 2004–2006 the number of undernourished people increased in all regions except Latin America and the Caribbean and is estimated to be 1.02 billion today (FAO 2009).
- The global atmospheric CO_2 concentration increased from the preindustrial level of 280 to 379 ppm in 2005. As a consequence of the accumulation of anthropogenic greenhouse gases (GHGs) in the atmosphere, the global mean surface temperature increased by 0.76°C from 1850–1899 to 2001–2005 (IPCC 2007a).
- Biodiversity, which provides an existential contribution to human welfare and livelihood, is decreasing at alarming rates (Millennium Ecosystem Assessment 2005). Between 10% and 50% of the higher taxonomic groups (mammals, birds, amphibians, conifers and cycads) are currently threatened with extinction. The main causes are habitat changes owing to land-use change, climate change, invasive alien species, overexploitation and pollution.

Human societies are concerned about these changes and their possible effects on the future availability of natural resources such as food, timber and freshwater. These concerns are reflected in several international agreements and regulations addressing better management of natural resources and improvement of the framework conditions. The most important political milestone toward international agreements on the sustainable management of forests resources was the United Nations Conference on Environment and Development (UNCED) in 1992 in Rio (Earth Summit), where several conventions and principles were adopted. The definitions, principles and standards formulated in these documents have many direct and indirect consequences for forest management and development of silvicultural concepts. Four of the most influential documents with direct influence on silviculture should be mentioned here exemplarily:

- The Convention on Biological Diversity (CBD 1992) commits the 168 signature states to support the three main objectives of the convention which are (1) the conservation of biological diversity, (2) the sustainable use of its components and (3) the fair and equitable sharing of the benefits arising from the utilization of genetic resources. As one concrete measure toward these objectives, Article 8 of the convention requires, for instance, that the countries prevent the introduction of alien species which threaten ecosystems, habitats or species and endeavor to provide the conditions needed for compatibility between present uses and the conservation of biological diversity and the sustainable use of its

components. In 2000, the Convention on Biological Diversity adopted 12 principles, which also consider local developmental needs and stress the importance of landscape-scale issues in managing natural systems (COP5 decisions). In 2004, the Addis Ababa Principles and Guidelines for the Sustainable Use of Biodiversity were adopted, which also address a number of issues related to biodiversity in managed systems (CBD 2004).

- The Framework Convention on Climate Change (UNFCCC 1992) with its follow-up document, the Kyoto protocol, emphasizes the role of forests as important reservoirs for carbon and their function as sinks for or sources of GHGs, especially CO_2, as influenced by forest management. The Clean Development Mechanism (CDM) of the Kyoto protocol and the Reducing Emissions from Deforestation and Forest Degradation (REDD) mechanism, which is actually under discussion as a new mechanism in the post-Kyoto agreement, offer new options for tropical forest management which may allow several barriers to be overcome that are currently restricting sustainable use of tropical forests in many cases.
- Agenda 21 (UN 1992a), which defines the objectives to sustain the multiple roles and functions of all types of forests, forest lands and woodlands as well as to enhance the protection, sustainable management and conservation of all forests, and the greening of degraded areas, through forest rehabilitation, afforestation, reforestation and other rehabilitative means. Another aim is to ensure the ecological, economic, social and cultural role of forests. It also endorses the participatory role of local communities in decision-making in sustainable forest management.
- The “Non-legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests” (Forest Principles) (UN 1992b), with its 17 points, reflects the global consensus on forests and applies to all types of forest, natural and planted, in all geographical regions and climatic zones. The principles encompass that states have the sovereign right to utilize, manage and develop their forests in accordance with their own development needs. Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations. Furthermore, the potential contribution of plantations of both indigenous and introduced species for the provision of fuelwood for household and industrial wood should be recognized as should the role of planted forests and permanent agricultural crops as sustainable and environmentally sound sources of renewable energy and industrial raw material, which shall be enhanced and promoted.

Although in the past environmental policies have been poorly considered and integrated in national policies, this has changed. Since UNCED in 1992, the countries have developed regional and international criteria and indicators that allow them to measure and monitor successes or failures in achieving sustainable forest management (Siry et al. 2005). Furthermore, a multitude of governmental and nongovernmental organizations with distinct but distinguished objectives is

critically observing silvicultural activities in tropical forests so that failures or ecological sins will be most probably identified and made public, which – owing to public and economic pressure – can put forest enterprises at risk. This “watch-dog” function of nongovernmental organizations is supported by the excellent new technology of high-resolution remote sensing.

In addition to the legal and societal framework conditions for forest management environmental conditions are also changing with different scales of intensity and time, resulting in direct or indirect effects on ecological processes and thus requirements for silvicultural treatment. Examples for such changes are the increasing CO_2 concentration in the atmosphere with the resulting global climate change (IPCC 2007a), loss of genetic resources owing to continuing loss of species and biodiversity (CBD 2004) and anthropogenic imissions into the ecosystems (Boy and Wilcke 2008; Boy et al. 2008; Fabian et al. 2005).

Consequently, silvicultural concepts and techniques cannot only be directed toward the objectives of the forest owners but must also consider the manifold societal demands as well as the ecological requirements arising from environmental changes. Therefore, they must be critically reviewed against the background of the new aspects and evaluated concerning their ability to meet the expected requirements. For instance, protectionist actors often accuse silviculturists of not having the technical knowledge required to satisfy the new and multiple demands without endangering the resource. Many forest managers, on the other hand, are convinced that the technical solutions to the challenges of sustainable forest management already exist and that it is only a matter of applying them appropriately (Bruenig and Poker 1989). However, often either the empirical evidence for the latter is lacking or the practices demonstrated by research are not applied by the timber companies, even if they are incorporated into forest management regulations (Embrapa/CIFOR 2000 cited in Olegário et al. 2008).

As a consequence of the above-mentioned aspects many realities for management of tropical forests have changed and it is important that silviculturists are aware of the changes and the resulting demands. The following sections will review in more detail some of the new aspects with paramount impact on forest management.

6.2 New Perspectives on Biodiversity and Conservation Management

The importance of biodiversity has been emphasized at different political levels through many international conventions and agreements promoting sustainable forest management (e.g., Montreal Process, Pan-European Process) as well as on commercial levels as part of certification schemes. For a long time the role of biodiversity has been recognized only in nature conservation but not in forest management (Chap. 4). Only recently, its recognition regarding rather technical aspects such as tropical silviculture has been growing. Similarly, for a long period

of time the establishment of protected areas and parks has been considered the most promising option to ensure the continued existence of natural landscapes and ecosystems as well as of the genetic bases of tropical forests. Meanwhile, 12% of the world's forests (460 million hectares) are designated for conservation of biological diversity (FAO 2010). However, there is evidence that thousands of species are likely to disappear when biodiversity outside protected areas is neglected (Putz et al. 2000). Furthermore, there is also increasing opposition from forest dwellers to forest reserves that restrict the traditional access to and use of the natural forest resources. The disregarding of these rights was one reason to exclude "avoided deforestation" projects from the Kyoto protocol's CDM in the first commitment period. Hence, conservation through careful use, e.g., biodiversity-sensitive silviculture in managed forests, is increasingly accepted as a valuable option in successful conservation strategies (Putz et al. 2000; ITTO, IUCN 2009).

Against this background, many traditional and well-established silvicultural practices have to be reevaluated concerning their impact on biodiversity and conservation as well as on environmental services and functions. Because conservation of biodiversity in timber production forests depends highly on the way in which they are managed (Campos et al. 2001), much more attention has to be given to techniques that have been widely disregarded so far, e.g., proactive prevention measures (e.g., against fire) and postharvesting activities (Chap. 12). Several management options that contribute to the maintenance of biodiversity or to limiting negative effects of silvicultural interventions have also been presented by Putz et al. (2001): seed tree retention, modifying the seed beds for germination, mechanical scarification, herbicide treatment, enrichment planting, liberation thinning, vine cutting and mimicking natural disturbances. For many forest managers, except in dry forests, reduced-impact logging (RIL) has already become a standard as it does not only reduce incidental environmental damage and conserve biodiversity, it also contributes to improved sustained yield and carbon offset (Chap. 16). RIL largely contributed to an increase in the area of natural forests under sustainable management from one million hectares in 1988 (Poore et al. 1989) to about 36 million hectares by 2005 (ITTO 2006). Bawa and Seidler (1998) concluded in their review of natural forest management that the extent to which it can be expected to conserve biodiversity depends on several factors, including the initial structure of the forest, the scale and intensity of operations in space and time and the geographical configuration of managed forest areas within the matrix of undisturbed primary forest. They favor increased support for management of secondary forests, restoration of degraded lands, and plantation forestry as silvicultural means of retaining the diversity of tropical forest communities.

Carrying out silvicultural treatments in conjunction with logging not only reduces costs, it also reinforces the idea that logging can be silviculturally useful. As soil effects and damages to the remaining stand increase with logging intensities, silvicultural interventions should be moderate and concentrated in small areas, which will also help to reduce costs. Owing to progress in forest planning and monitoring (satellite images, digital landscape models) as well as in logging technology (e.g., cable or helicopter yarding) which allow, for example, better

design, construction and maintenance of road networks, new means to limit damaging effects of silvicultural interventions are also available at the management level. As monitoring and controlling are more and more becoming integral parts of management, silviculturists will be enabled to steadily learn from successes and failures. For example, for biodiversity conservation in a comprehensive *Acacia mangium* plantation in Sarawak, a geographic information system was used to plan, implement, monitor and control activities in all planted compartments as part of an integrated plantation management system (ITTO, IUCN 2009). A landscape-scale map shows the mosaic pattern of natural and planted forests, and large and small conservation set-asides.

With the criteria for modern approaches to forest management considering conservation and biodiversity aspects as formulated in the certification schemes, for instance by the Forest Stewardship Council's Principles and Criteria for Forest Stewardship, new standards are set that cannot be disregarded by silviculturists even under noncertified conditions because markets will force them to be sensitive to the growing environmental concerns of global consumers and shareholders (Laurance 2008).

During the last two decades forest science has substantially improved the understanding of the effects of silvicultural activities in many forest ecosystems around the world (Bawa and Seidler 1998; de Graaf et al. 1999; Finkeldey and Ziehe 2004; Günter et al. 2008; Johns 1992; Kobayashi 1994; Lambert 1992; Pariona et al. 2003; Weber et al. 2008; Wilcke et al. 2009). Putz (Chap. 7) stresses also the need for clear differentiation among biodiversity aspects on different scales (landscape, ecosystems, community, species and genetic levels) as this has a direct influence on the evaluation of specific measures under different economic conditions and spatial levels. Because of better training and easier access to information, forest managers will be able to apply more sophisticated silvicultural concepts in the future.

6.3 Climate Change

Forest management can increase or decrease carbon flows between forests and the atmosphere and thus contribute to both acceleration and mitigation of atmospheric CO_2 accumulation, which is a dominant cause of climate change. Tropical forests account for about 40% of the carbon in the terrestrial biomass and 30–50% of terrestrial productivity (Dixon et al. 1994; Phillips et al. 1998; Watson et al. 2000). Forest destruction and degradation, predominantly in the tropics, accounts for about 17% of the total anthropogenic GHG emissions (IPCC 2007a). Because the role of forests as a sink for or source of carbon is a function of storage, accumulation or loss of biomass, any activity or management practice that changes the biomass in an area has direct effects on the carbon budget (Moura-Costa 1996). Putz et al. (2008) state that the potential for emission reductions through improved forest management is at least 10% of that obtainable by curbing tropical deforestation.

Consequently, management of tropical forests is high on the political agenda to mitigate climate change.

Furthermore, climate change is likely to have enormous impacts on tropical forests and their biodiversity (ITTO, IUCN 2009), which will also influence their capability to sequester carbon. All silvicultural activities must therefore also contribute to ensuring the potential of forests to adapt to the expected changes. Thus, climate change is a challenging new aspect for silviculture in tropical forests as it requires sustainable forest management to be reconciled with mitigation and adaptation management. To enable forest managers to cope with this situation, they need a clear decision on whether the management objective is to maintain carbon storage, to prevent carbon losses or emissions, or to actively remove CO_2 from the atmosphere. If a mixture of objectives is intended, a clear hierarchy of the different management targets is required.

In the following sections the main topics linked with the different management objectives are presented.

6.3.1 Management for Mitigation

The central means in managing forests for mitigation are maintaining high carbon stocks in natural forests, increasing the amount of carbon held within managed forests and reducing carbon losses due to management interventions.

The most effective measure to maintain high carbon stocks is to conserve standing forests, especially old-growth forests, which are high in carbon. However, this option disregards the multiple demands of the people living in or from the forests, or both. Thus, it is important to determine if a forest is going to be used for a mitigation purpose only or also for provision of products, income or services other than carbon. In the first case, the cost for the abandonment of utilization must be compensated for by the sale of the corresponding carbon credits. In the latter case, carbon credits could be a supplemental source of income if "additional" measures are applied or omitted that result in reduced emissions compared with "business as usual." In any case, sound information on trade-offs between management for products (timber, nonwood forest products, etc.) and for carbon is needed: first to decide what type and intensity of silvicultural treatment should be chosen, and second for the proper accounting of the corresponding carbon effects. Ashton et al. (2001a) claim that a unique set of silvicultural treatments should be tailored for the biophysical and social characteristics of each site to be able to effectively manage forests for carbon. However, it should be kept in mind that any extraction of timber from a forest will result in a reduction of its carbon stock, at least for a certain period of time.

There are various options for and intensities of silvicultural treatments that can be applied both before and after logging operations to promote increased carbon storage, or to improve the overall health and productivity of a forest (Table 6.1). However, all of them require sufficient knowledge of the current status of a stand

Table 6.1 Forest management options for mitigation greenhouse gas emissions and increased carbon storage

Management option		Potential other (noncarbon) effects
Objective: Increasing biomass in existing forests		
Increasing rotation length or intervention intervals	+	Increased ecological values
	–	Transient renunciation of income and products; increasing risk of catastrophic breakdown
Increasing stocking density (e.g., by reduced thinning or underplanting)	+	Higher biomass, better economic yields in the future
	–	Reduced stability, transient renunciation of income and products
Increasing amount of deadwood volume	+	Increased habitat values
	–	Transient renunciation of income and products
All aged forests with selective logging	+	Increased stability and habitat values; more continuous income
	–	Higher management skills required
Increasing forest growth (e.g., by fertilization or change of species composition)	+	Higher productivity, more and earlier income
	–	Loss of naturalness, eventually N_2O emissions
Postharvesting measures (e.g., weed control, planting)	+	Faster regeneration, better growth conditions
	–	Increased management costs
Enrichment planting in secondary forests	+	Higher proportion of valuable tree species, higher income
	–	High complexity, intensive management and high level of skills required
Objective: Preventing carbon losses		
Reduced impact logging (e.g., vine cutting, adapted machinery, careful planning and timber extraction)	+	Less erosion and compaction of soil, less damage to the remaining stand
	–	Higher costs and level of management skills required
Improving forest health and stability (e.g., appropriate species choice, mixed stands)	+	Higher stability, reduced losses due to pests and diseases, better adaptation to climate change; species with high wood density and quality which allow assembly of long-lived wood products
	–	Increased management costs
Prevention of forest fires	+	Increased safety and income
	–	Higher management costs, aggravated establishment of seedlings
Continuous cover forests	+	Increased stability and ecological value, flexible income
	–	Higher level of management skills required
Reduced ground preparation (fire, ploughing)	+	Reduced soil respiration, erosion and emission of greenhouse gases (N_2O, NO_x, NH_3, N_2)
	–	Aggravated establishment of seedlings
Correct timing and intensity of fertilization	+	Avoided emissions of N_2O, NO_x and NH_3, and eutrophication of watercourses
	–	Reduced growth
Adequate thinning	+	Reduced windthrow and anaerobic conditions owing to excessive thinning; reduced mortality owing to insufficient thinning
	–	Initial application of the thinning will result in a loss of standing aboveground carbon because of the reduction in the site's gross carbon volume
Improving pest control	+	Better productivity and reduced losses
	–	Pollution of soils or water

+ positive effects; – negative effects (according to IPCC 2003, changed)

and the impacts of silvicultural interventions on carbon in biomass and soil as well as on other GHGs, e.g., CH_4 and N_2O, which might be released as a consequence of a measure applied. Cid-Liccardi and Kramer (2009) state that efforts to maximize carbon uptake and to reduce carbon losses need to be based on site dynamics and the application of silvicultural practices that are based on forest type and site characteristics. Furthermore, it is recommended that silviculture should consider landscape-scale effects as well because the maximum amount of carbon can be sequestered without compromising the long-term sustainability of the carbon storage when the stands are managed within a functional landscape matrix. This is also necessary to identify and consider zones of high carbon or other ecological values, e.g., for biodiversity or watersheds (Ashton 2003). Sist et al. (2003) stress the need to look also for harvesting impacts and trade-offs across larger forest landscapes, to expand RIL beyond silvicultural concepts and to ensure the maintenance of other forest goods and services. According to Ashton (2003), the landscape-scale template should reflect an integrated network of stands allocated to production and protection, with the focus on maximizing carbon storage within the landscape.

Table 6.1 provides an overview of management means for maintaining or increasing carbon stocks in existing forests or reducing management-induced losses.

Moura-Costa (1996) presented a table with estimated carbon offsets that can be achieved by several activities in the tropics over different time periods. The values range from 1–2 tons ha^{-1} (time frame 1 year) for soil improvement, to 20–30 tons (1 year) for soil protection, 250–350 tons for fire protection (undefined time frame), 35–150 tons (2 or 10 years) for RIL, 90–150 tons (30 years) for silvicultural treatments, 90–150 tons (20 years) for agroforestry, 150–280 tons (50–70 years) for enrichment planting with hardwoods and 100–200 tons (10–20 years) for plantations of fast-growing species. The offsets are calculated as the difference between the carbon accumulated in planted vs. untreated forest, or between conventional logging vs. RIL as the latter results in less damage to the residual stand, and more healthy stands, especially when aerial yarding by cable or helicopter is applied. Nabuurs and Mohren (1993) compared carbon-fixation rates of 16 global forest types under different management and found that management of selectively logged tropical rain forests is one of the most effective means. Ideal candidates for rehabilitation through enrichment planting with high wood density, long-lived canopy trees for carbon sequestration are, for instance, many logged-over and second-growth forests (Cid-Liccardi and Kramer 2009). Monospecific plantations with fast-growing species can sequester carbon in a very efficient way, but bear high risk of losses due to fires, pests or diseases.

When tropical forests are to be managed for carbon, treatments that may affect, expose or reduce soil carbon should be minimized and treatments that free growing space for desired species should be encouraged (Cid-Liccardi and Kramer 2009). Because the highest losses of carbon are caused by damage linked with badly planned or executed logging operations (Putz and Pinard 1993; Putz et al. 2008), reduction of avoidable logging damage to residual forest, soils and critical ecosystem processes through application of RIL must become a self-evident element in silvicultural planning (Pinard and Putz 1996). The means employed under RIL

cover a multitude of activities ranging from identification of sensitive areas to careful planning of roads and skid trails, use of selective felling instead of clear felling, erosion control measures, preharvest liana cutting and training of loggers for directional felling or fire prevention and control. Comprehensive and detailed overviews of RIL and its effects and costs have been provided by Enters et al. (2002) and Dykstra and Heinrich (1996).

Despite the many undisputable benefits of RIL, with regard to CO_2 mitigation, its application requires great knowledge on the impact and timescales of each measure. For instance, liana removal affects carbon storage because it increases the light available to trees and reduces competition, allowing growth rates and carbon to increase in the stand (Wadsworth and Zweede 2006; Keller et al. 2007; Zarin et al. 2007). However, the positive benefits of liana removal persist only for a few years, and repeated treatments are required over a cutting cycle (Peña-Claros et al. 2008a, b). Other measures, such as prescribed burning and soil scarification for exposure of mineral soil to encourage regeneration, can even have negative effects on carbon storage if done inappropriately because they could reduce soil organic matter. On the other hand, carbon emissions linked with site preparation may be compensated for by a higher increment of planted trees compared with untreated trees (Moura-Costa 1996). Sist et al. (2003) concluded from their studies in mixed dipterocarp forests in Borneo that RIL techniques cannot guarantee silvicultural sustainability when solely based on a minimum-diameter cutting limit. They suggest three silvicultural rules to ensure sustainable management (1) to keep a minimum distance between stumps of about 40 m, (2) to ensure there are only single tree gaps using directional felling and (3) to harvest only stems with 60–100 cm diameter at breast height.

However, besides the mitigation potential of forest management described, it should be mentioned that the key opportunity in tropical regions is the reduction of carbon emissions from deforestation and degradation.

6.3.2 Management for Adaptation of Forests to Climate Change

When managing tropical forests for mitigation, one has to consider that the effects of climate change, e.g., regional drying and warming (Salati and Nobre 1991), increasing frequency and intensity of extreme weather events (IPCC 2007a), possible intensification of El Niño phenomena (Sun et al. 2004), changes in phenological relations, or loss of biodiversity (IPCC 2007b), may limit or even reverse the sink effects of the forests. Especially the huge carbon stocks in mature tropical forests may be vulnerable to disturbances induced by climate change. To reduce the risk of such carbon losses, silvicultural concepts and strategies must strive to maintain the ability of forests to adapt to climate change. This may require alterations of established management regimes. Forest management will need to be highly adaptive, which will require good and up-to-date information about what is happening in the forest (ITTO, IUCN 2009). However, as climate change in the

tropics is still associated with many uncertainties and no empirical evidence is available, it must be assumed that silvicultural adaptation strategies will not be substantially different from other risk-reducing strategies, and thus should strive to reduce vulnerability to pests, diseases and abiotic damage by ensuring forest health and ecosystem diversity as a prerequisite for the ability (resilience) of the forest to recover after disturbances (Adger et al. 2005; Van Bodegom et al. 2009). Cid-Liccardi and Kramer (2009), for instance, state that in the long term a species-rich forests with a diverse vertical structure will be more resilient to catastrophic disturbances, and therefore to carbon loss. On the basis of Smith et al. (1997) and Ashton et al. (2001a, b), they conclude that these objectives can be most likely achieved by regeneration via a shelterwood system and its variations around structural retention and age class. An excellent overview of silvicultural practices to maintain and enhance the adaptive capacity of natural and planted tropical forests was provided by Guariguata et al. (2008).

It has to be mentioned as well that some adaptation measures, e.g., regenerating old, mature stands or understory removal for fire prevention, may conflict with the objective of maximizing carbon storage as the highest stocks are achieved in old forests with high biomass, which are considered to be more vulnerable to disturbances. Management for adaptation must also consider the landscape scale, for instance by making an effort to maintain and improve the connectivity between forest fragments or habitats to ensure minimum viable populations. Furthermore, it requires intensive monitoring to quickly detect and tackle outbreaks of pests and diseases, and changes in the dynamics or composition of the forests (Van Bodegom et al. 2009).

Consequently, Phillips et al. (1998) called for a dedicated large network of permanent biomass plots to obtain insight into the future role of tropical forests in the carbon cycle. The incorporation of multiple variables into ecosystem and forest models for tropical forests can also contribute to a better understanding and consequently better management of the carbon fluxes and climate change effects (Nightingale et al. 2004). For this purpose, intensive research on the positive and negative feedbacks of possible impacts of climate change, such as droughts, windstorms, biotic pathogens, and fires, on forest dynamics and carbon stocks is still required (Meister and Ashton 2009).

6.4 Increasing Importance of Goods and Services Other Than Timber

6.4.1 Nonwood Forest Products

Gathering forest resources other than wood, such as berries, mushrooms, fruits, herbs, and bush meat, to provide food, energy, or construction material has been practiced by humans since historical times. However, since the 1980s NWFPs have achieved renewed and increased interest on a global scale as an additional income-generating

option (García-Fernández et al. 2008; Chap. 10). Although information from many countries is still missing and the true value of subsistence use is rarely captured, the value of NWFP removals in 2005 is reported to amount to about US $18.5 billion (FAO 2010). Consequently, integration of timber and nontimber forest uses is considered to offer new opportunities for subsistence and market economies of rural communities to enhance their well-being and to reduce the risk of losses due to a more diverse portfolio of assets. NWFPs can be a significant complementary asset to timber production, particularly in low-wage, rural economies. Several studies have shown that in combination, net present values can double or even triple, with NWFPs often providing most of the income (Godoy et al. 1993; Boot and Gullison 1995; Ashton et al. 2001b). Peters et al. (1989) stated that the potential long-term economic returns from forests managed for NWFPs are greater than the returns from timber or forest conversion to agriculture. Thus, NWFP management has also caught the attention of conservationists as a means of ensuring forest conservation and as alternative to conversion (Hiremath 2004).

Including NWFPs in diversified forest management plans is increasingly used in sustainable forest management to offset the costs of RIL. However, skeptics question the extent to which the economic returns from NWFPs are sufficient to compensate for the costs of applying RIL (Barreto et al. 1998; Pears et al. 2003) and corresponding silvicultural practices, e.g., enrichment planting or liberation thinning, needed for sustaining timber production over the long term (Schulze 2008; Wadsworth and Zweede 2006).

For silviculture, managing different types of products (timber and NWFPs) is a new challenge as it requires different knowledge and skill sets which are still segregated among different forest users. To be able to cope with this challenge, managers must extend their silvicultural expertise from forest management to agroforestry and farming practices. Consequently, such aspects should be included in modern tropical silvicultural education and training. However, NWFPs are still predominantly treated in relative isolation (Lawrence 2003 cited in Guariguata et al. 2010). Although Whitmore (1990) stated that incorporation of NWFPs with timber extraction was common until the middle of the last century, data on the production and reproduction of NWFPs within timber management as well as integration of silvicultural interventions for NWFP species in overall forest management are rare or nonexistent (Panayotou and Ashton 1993; Chap. 10).

To be able to sustainably integrate nonwood forest species management in silvicultural concepts, their ecological and productive characteristics must be explored and tested. Only little is known about NWFP harvesting impacts and the available information seems not consistent. Ticktin (2004) reviewed 70 studies that quantified the ecological effects of harvesting NWFPs from plants and concluded that the tolerance of NWFP species to harvesting varies according to life history, the part of plant that is harvested, environmental conditions and the management practices used. Moreover, the impact can vary from the level of genes to individuals, populations, communities and ecosystems (Hall and Bawa 1993; Ticktin 2004). Although a close relation to logging intensity has been established, further assessments of the diverse harvesting impacts are needed. Furthermore, specific

silvicultural systems for NWFPs are essential for sustainable management (Hall and Bawa 1993). For instance, to promote population persistence of specific NWFPs, sparing of individuals, size restrictions, overstory light management, thinning, transplantation, coppicing and replanting of plant parts can be adequate management practices (Ticktin 2004).

Guariguata et al. (2010) emphasized six topics to be considered as key components of sustainable forest management integrating NWFPs (1) integration of NWFPs in inventories (yields, mapping), (2) ecology and silviculture for timber and NWFPs (effects of logging intensity and corresponding changes in forest structure, radiation, soil), (3) conflicts in the use of multipurpose trees, (4) wildlife conservation and use (habitat changes, increased access), (5) tenure and access rights (types of rights, multiple right holders) and (6) product certification (ecological and social constraints). They concluded that compatible management has to be inherently multifactorial and context-dependent.

Sustainable extraction and management of timber and NWFPs is influenced not only by silviculture but also by many other factors. Guariguata et al. (2010) published an indicative list of factors, with, e.g., habitat overlap, length of rotation cycles, property rights, local governance, and market chains. Consequently, barriers for successful adoption of silvicultural practices are rarely just technical in nature but depend on diverse perspectives of individuals (Walters et al. 2005). As some user demands may conflict with others, participation of the main stakeholders in forest planning is required to balance all expectations. However, this will make planning even more complex. To make integrated management of timber and NWFPs more feasible, attractive and competitive for other land users and thus to avoid forest conversion, it may also be necessary to increase the number of species and products utilized from tropical forests. Actually, only about 150 NWFPs are of major significance in international trade although approximately some 4,000 botanicals species enter international markets (Chap. 10). Especially for small-scale operations, integration of a wide array of goods and services would be beneficial (Campos et al. 2001). As a high proportion of NWFP goods are still collected from the wild, domestication measures will have to be applied for many species to increase the efficiency of their management (Bhattacharya et al. 2008). However, one should proceed with caution because highly valued NWFPs may increase the risk of gradual conversion of forests into tree-gardens or agroforestry systems (Michon et al. 2007) or the setting up of plantations. For more details on the silvicultural options of NWFP management see Chap. 10.

Several promoters of multiple-use forest management emphasize that by incorporating many forest goods and services and by considering the interests of multiple stakeholders, a social and financial advantage can be gained over timber-dominated models (Ashton et al. 2001a; Campos et al. 2001; Hiremath 2004; Wang and Wilson 2007). According to the FAO (2010), the area designated primarily for productive purposes has already decreased by more than 50 million hectares since 1990, whereas that for multiple uses has increased by 10 million hectares in the same period.

6.4.2 Biofuels

In many tropical countries fuelwoods traditionally play an important role. For instance, in Africa fuelwood is the dominant source of heat energy in rural households, where it is used for cooking, heating and steam raising (Chap. 24). However, since the use of fossil fuel is causing 57% of the total GHG emissions (IPCC 2007a), switching from fossil fuels to biomass fuels will play an increasing role in strategies to reduce GHG emissions. In this context the tropics receive special attention because of the high production rates of up to 40 tons ha^{-1} year^{-1} which can be achieved in this region (Chap. 9). Although a large proportion of "modern" fuelwood comes from agricultural areas or from nonwoody biomass, the situation also provides new opportunities and challenges for silviculture.

On land that has not been available for forestry so far (e.g., grassland, fallow land, marginal and abandoned land) new forests could be established with the sole objective of biomass production. Grainger (1990) considered fuelwood production in a fully sustainable cyclic system as the most promising option for carbon sequestration in the long run. Consequently, silviculture must develop concepts to produce biomass for energy purposes under different conditions in an ecologically, economically and socially sustainable way.

One promising option is biomass production in short-rotation forestry. Although short-rotation forestry has a long history, e.g., coppice as an ancient silvicultural system to grow small wood for fuel, charcoal or fencing, there is a need to review the concepts against the background of the new practices and technologies in production and processing. Essential silvicultural features in this context are, e.g., adequate stocking densities to achieve fast site occupancy and high mean annual increments, tree breeding programs, use of fertilizers, integrated pest and disease management, and mechanized harvesting (Mead 2005).

Another important aspect is the identification of suitable species for different types of land and environmental conditions, which are adapted to the sites and are easy to establish, show good growth rates and coppicing ability and produce high-calorific wood (NAS 1980; Nair 1993; Mead 2001, 2005). Moreover, good understanding and monitoring of the nutrient cycles, especially if whole tree harvesting will be applied, is required. Silviculture has to explore and develop ways in which biofuels can be produced and harvested in the context of larger landscapes and all forest resources without violating the ecology or the demands of local societies, especially for food production.

Biofuels can also offer new opportunities for traditional timber management, as residues from harvesting that would otherwise be left to decay could be considered as valuable by-products to increase the environmental and financial benefits of bioenergy (Hwan Ok Ma 2007). If biomass production is additional and sustainable, it can also generate supplemental income by generating carbon credits. However, it has to be considered that harvesting of logging residues has silvicultural implications, apart from soil fertility concerns (Asikainen et al. 2002).

More detailed information on silvicultural aspects of bioenergy production is provided by Onyekwelu and Fuwape (Chaps. 9 and 24).

6.4.3 Ecosystem Services

Apart from the delivery of marketable goods such as timber, NWFPs and biofuels, natural and managed forest ecosystems also provide many services that are in demand from different interest groups but can hardly be merchandized directly by the forest owners on local markets. The Millennium Ecosystem Assessment (2005) distinguished among regulating (air quality, climate, water), cultural (recreation, spiritual enrichment), and supporting (nutrient or water cycling, photosynthesis) services. Some of these services are scale-dependent; for instance CO_2 sequestration is more effective at a global scale, whereas maintenance of water quality or erosion protection is more locally or regionally relevant. Some services can be ensured by the pure existence of a forest (e.g., photosynthesis), whereas others rely on or can be improved by silvicultural activities (e.g., recreation).

During recent decades a shift from monostructured silviculture focussed on procedures to achieve high wood yields for a few economically attractive species toward multiple-use forest management considering timber, NWFPs, and environmental services has been observed (Bertault et al. 1995). However, owing to the persistent deforestation and degradation together with the steadily rising demand on natural resources, it is becoming critical to embrace all requirements in management of tropical forests. Thus, there is a growing need to promote concepts for sustainable extractive uses alongside the persistence of ecosystem services, especially biodiversity (Millennium Ecosystem Assessment 2005).

For a long time it was assumed that provision of forest services follows in the wake of timber production (Glück 1987). This meant that the production of timber also encompasses other objectives, such as sustaining the function and dynamics of ecosystems, maintaining ecosystem diversity and resilience, and provision of various ecosystem services of value to mankind (Coates and Burton 1997). However, several forest management operations, especially in the tropics, affect ecosystem services (Olegário et al. 2008) or are not compatible with specific services. Because many environmental services are considered as public goods, they were taken for granted. The direct costs of the forest owners related to the provision of environmental services, e.g., special management interventions required or higher costs of forest operations due to management restrictions, were a major barrier for better consideration in silvicultural planning and practice.

With increased awareness about the environmental services provided by forests and the perceived scarcity, the appreciation of beneficial forestry activities and the readiness to pay for them have improved. Thus, payments for environmental services (PES) emerged as an innovative means to compensate service providers for their expenses to maintain or achieve a requested level of environmental service provision. The most dynamic and advanced PES types so far are those for carbon

sequestration, biodiversity conservation, watershed protection, and landscape beauty (García-Fernández et al. 2008). PES offer a great chance to facilitate sustainable forest management, or to make it competitive with other land uses and thus to avoid further forest destruction and loss of the forest environmental services. A study on how this can be achieved practically was presented by Knoke et al. (2009) using an example of Andean Ecuador. Despite progress in recent years, there are still many methodological problems, especially regarding the allocation of concrete economic values to specific services (Pirard and Karsenty 2009). To ensure that the benefits of managing a forest area in a sustainable manner including environmental services will really be captured by the forest owners, it is necessary to fill in the existing gaps of ecological knowledge about the effects of specific silvicultural techniques on the provision of environmental services. Thus, there is an urgent need for corresponding research that also involves monetary evaluation of silvicultural aspects. For example, Smith and Applegate (2004) stated that both opportunity costs of shifting from conventional logging to improved practices and the long-term carbon and biodiversity benefits of improved forest management have been underestimated.

For silvicultural planning it is essential to know which special environmental services are in demand and if they should be provided by integrated management of a total given forest area or if segregation into different districts is possible. This implies that the expected environmental services as well as the different stakeholders must be clearly identified and included in management planning. Last but not least, it has to be clarified if the compensation will be paid on an individual basis based on the application or omission of specific procedures or as a flat rate which is independent of the particular costs. Anyway, production of more diverse forest values requires the consideration of the fine-scale variability within forest stands and a better understanding of the spatial and temporal responses of forest ecosystems to manipulation (Coates and Burton 1997). Silviculture has to provide procedures that meet the objectives of timber production without compromising environmental services.

Depending on the spatial scale, silvicultural planning must involve the identification of sensitive areas or structures, e.g., to avoid downstream effects on soil and water.

Box 1: Gap-Based Models as a Tool to Understand Fine-Scale Ecosystem Responses to Silvicultural Manipulations

Coates and Burton (1997) proposed employing gap-based approaches to study stand responses to silvicultural manipulations that "(1) aids development of cutting prescriptions that maintain functional mature or old-growth conditions; (2) refines and extends our understanding of how biological structures, organisms and ecosystem processes are affected by fine-scale variation within stands…" Such studies could help to identify optimal gap sizes, distribution and frequencies that are adapted to different stand structures and site conditions. Table 6.2 provides an overview of the characteristics of tropical and subtropical ecosystems that are related to different gap attributes.

(continued)

Table 6.2 Examples of characteristics of tropical and subtropical ecosystems as affected by gap attributes

Ecosystem characteristic	Gap attribute					References
	Presence	Size	Position	Age	Substrate	
Tree species establishment/density/composition						
Tropical moist forest, Panama	–	+	–	–	+	Putz (1983)
Tropical moist forest, Panama	–	+	–	+	–	Brokaw (1985, 1987)
Tropical cloud forest, Costa Rica	+	0	–	0	–	Lawton and Putz (1988)
Amazonian forests, Venezuela	0	0	0	–	–	Uhl et al. (1988)
Subtropical broadleaved, India	+	+	–	–	–	Barik et al. (1992)
Tropical cloud forest, Ecuador	+	+	–	–	+	Kuptz et al. (2010)
Birds						
Richness/composition	+	–	–	–	–	Schemske and Brokaw (1981)
Guilds/species	+	+	–	–	–	Levey (1988)
Small mammals						
Bat species	+	–	–	0	–	Crome and Richards (1988)
Insects						
Level of attack	+	–	–	–	–	Harrison (1987)
Abundance	+	–	–	–	–	Shelly (1988)
Population structure of moths	+	+	–	–	–	Günter et al. (2008)
Epiphytes	+	–	–	–	–	Günter et al. (2008)
Irradiance						
Tropical forest, Costa Rica	+	–	+	–	–	Denslow et al. (1990)
Tropical cloud forest, Costa Rica	–	+	–	–	–	Lawton and Putz (1988)
Subtropical broadleaved, India	+	+	–	–	–	Barik et al. (1992)
Tropical evergreen rain forest, Mexico	–	+	–	+	–	Dirzo et al. (1992)
Tropical cloud forest, Ecuador	+	+	–	–	–	Kuptz et al. (2010)
Climate parameters						
Air temperature (mean/min./max.)	0	0	–	–	–	Barik et al. (1992)
Humidity	+	0	–	–	–	Barik et al. (1992)
Soil parameters						
Surface soil moisture	+	+	–	–	–	Barik et al. (1992)
Soil temperature (mean/min./max.)	0	0	–	–	–	Barik et al. (1992)
Soil respiration	+	–	–	–	–	Günter et al. (2008)
Soil nutrient availability	0	0	0	–	–	Uhl et al. (1988)
Nutrient levels	+	–	–	–	–	Wilcke et al. (2009)
Phosphorus concentration canopy zone	0	–	–	–	–	Vitousek and Denslow (1986)
Phosphorus concentration root-throw zone	+	–	+	–	–	
Litter thickness/decomposition	+	+	–	–	–	Barik et al. (1992)
Fine root biomass	+	–	0	–	–	Sanford (1989)
	+	+	–	–	–	Sanford (1990)

Based on Coates and Burton (1997), extended
+ significant effect; 0 no effect; – not tested

Adapted cutting cycles and directional felling should also be minimum requirements. For the acquisition of PES, it will be necessary to clearly identify and assess the supplementary direct and indirect costs of activities that go beyond the “normal”

management for timber production, for instance the application of RIL techniques or postharvesting practices. Because biodiversity conservation is one of the environmental services most demanded, for PES forest managers must be capable of monitoring changes in both biodiversity and society's requirements for biodiversity and be capable of adapting their management accordingly (ITTO, IUCN 2009). Thus, there is high need for consideration of new subjects in silvicultural research, education and technical training, e.g., comprehensive land-use planning, efficient inventory and monitoring methods, participation of the local population, better integration of silviculture and harvesting, better consideration of low-abundance/low-value species, renouncement of the use of pesticides and herbicides, habitat management, and conservation (de Haan 2008). All these aspects should be linked with economic considerations related to the marketing of the resulting effects as ecosystem services.

6.4.4 Ecotourism

Many tropical forests play an important role as a resource of biodiversity and refuge for endangered species as well as for indigenous communities. This did not only increase their importance for conservation and recreation of local people but has also attracted the interest of ecotourism. This implies that as far as managed forests are concerned all silvicultural interventions have to be applied in a very sensitive way, which means that the general character of the stands must be maintained as naturally, biodiverse and attractively as possible, whereas obvious logging damage will not be compatible with ecotourism. In the context of ecotourism, much more attention must also be paid to landscape effects of silviculture and to the compatibility with the presence and abundance of attractive animals. Forests have to be considered as formative elements embedded in human-populated landscapes. This requires local people becoming involved in planning in participatory procedures. Adequate compensation would also allow specific activities to be applied, such as managing ornamental species, creation of apertures and outlooks, the creation of scenic roads or hiking corridors, and increasing the rotation length, that increase the value of a forest for recreation and ecotourism. In managed forests the income that can be generated by ecotourism has to be balanced against possible losses or increased costs due to, e.g., reduced removal volumes or growth rates, maintenance of infrastructure, or security aspects. Nevertheless several studies have shown that ecotourism can provide significant increases in the livelihood and purchasing power in rural communities (Wunder 1999; Tobias and Mendelsohn 1991).

6.5 Increased Requirements for Inventory, Monitoring and Planning

Adequate consideration of the specified aspects in silvicultural decision-making and controlling entails an increasing demand for detailed information. Today forest managers are expected to provide empirical evidence that their forests are well

managed or that a certain intervention does not harm ecological processes or ecosystem services. Thus, enhanced sustainable forest management requires credible verification and reporting (Siry et al. 2005). For many products and services a continuous chain of custody of ecological and social management standards is required today for successful marketing or approval under certain programs. As a consequence, the global forest area certified by one of the major certification schemes increased from 121 million hectares in 2002 to approximately 270 million hectares in 2006 (FAO/UNECE 2006).

To be able to fulfill the multiple demands and to provide the information requested by legal institutions, stakeholders, international markets or certifiers, efficient tools for inventory and monitoring of ecological, economic and social conditions must be developed. For instance, changes induced by specific silvicultural interventions have to be analyzed and documented at different temporal (from short term to long term) and spatial (from stand to landscape) scales. Under sustainable multifunctional forest management it is therefore necessary to include explicit spatial structures and objectives in planning and monitoring (Baskent and Keles 2005). Many forest functions are directly related to the characteristics of a forest, e.g., size, structure and shape. Furthermore, treatment in one forest unit may also influence adjacent units. A clear-cut, for instance, can increase the risk of wind damage, sunburn, or erosion in the neighborhood (Öhman 2001). Disregard of spatial characteristics can therefore result in lower yields, reduced water quality or habitat disruption.

The specified requirements are reflected in new methods and technologies, especially in the field of remote sensing, GPS and georeferencing. These new technologies enable forest managers to better keep track of the described development. Owing to progress in remote sensing, high-resolution images with comprehensive information on stand composition and structures, terrain, environmental conditions and soil are available. Geographic information systems allow direct interlinking of this information and characterization and analysis of spatial relationships among explicit management units at different scales (e.g., susceptibility for disturbances, or connectivity). Furthermore, growth and yield models (Vanclay 1994, 1995; Clark and Clark 1999; Huth and Ditzer 2000; Peng 2000; Ong and Kleine 1996), process-based ecosystem models (Mäkelä et al. 2000; Miehle et al. 2010), new bioeconomic models (Knoke et al. 2009) and management-oriented models to evaluate the effects of different management strategies (Huth and Ditzer 2001; Kammesheidt et al. 2002; Schelhaas et al. 2004) can be used to manage all information in an integrated way. Many decision-support models have been developed as well (Battaglia et al. 2004; FORSYS 2010; Iliadis 2005) to help forest managers to better structure and analyze the complex and sometimes chaotic conditions and to make decisions based on sound facts and the most recent scientific knowledge in a reproducible way. However, managers are still hesitating to really use them (Whyte 1996). Last but not least, negotiation-support models are available that assist the communication of the complex and sometimes conflicting aspects with the many actors and stakeholders and thus avoid conflicts, identify common

demands and views or rank multiple demands according to priorities (Van Noordwijk et al. 2001).

All the instruments described offer new opportunities to include the improved knowledge of ecosystem functioning in silvicultural planning and to make it more spatially explicit toward a kind of "precision forestry" (Farnham 2001). This makes it, for instance, feasible to give much better consideration to functional characteristics of tree species, keystone species, efforts to connect habitats and landscapes, energy and material flows induced by interventions, or interactions (e.g., complementarity) among different ecosystem components, which may lead to higher productivity or less risk. High-resolution monitoring of landscapes enables silviculturists to quickly detect and tackle outbreaks of pests and diseases, and to improve effective fire management. Nevertheless, to be able to assess the temporal stability of ecosystems under different silvicultural treatments and to identify feedbacks, many more long-term silvicultural experiments are needed.

6.6 Conclusions

Although timber production has been the dominant function of forests in the past, in recent years a more multifunctional and balanced view of forest management has become widely accepted. Recreation, health and well-being, biological diversity, mitigation of climate change and adaptation to it have been increasingly recognized as integral components of forest management. As most silvicultural practices have been developed not for these purposes but for improving the timber production of commercial species (Feldpausch et al. 2005), there is an urgent need to evaluate traditional concepts against the background of the new aspects and needs. Sustainable management of tropical forests requires the integration of ecological knowledge with social, economic and political-institutional constraints and options (Hooper et al. 2005). Consequently, silvicultural concepts must encompass a broad range of objectives as well as the full set of options to manage trees for special purposes, such as natural forests, plantations, agroforestry and trees in landscapes (Van Bodegom et al. 2009). Unfortunately, corresponding silvicultural research on timber species, NWFPs and ecosystem services is sparse or lacking, and the existing information is concentrated on only a few species and in particular regions.

Nevertheless, in the last two decades significant, substantial progress toward sustainable multifunctional management of tropical forests has been made, particularly in terms of designation of permanent forest estates, formulation of policies to guide forest management and establishment of management plans. Furthermore, a range of initiatives to accelerate the implementation of sustainable forest management have been adopted: certification schemes, voluntary partnerships, forest law enforcement and government efforts. Initiatives such as the voluntary codes of practice developed by the FAO and the International Tropical Timber Organization (ITTO) provide benchmark standards for managers (ITTO 2006).

In this context, silvicultural concepts for planning and application are needed that can be applied under spatially explicit conditions and that consider different levels of scale ranging from landscape to species and genes (see also Chap. 7).

References

Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across scales. Glob Environ Change 15(2):77–86

Ashton MS (2003) Regeneration methods for dipterocarp forests of wet tropical Asia. For Chron 79:263–267

Ashton MS, Peters C (1999) Even-aged silviculture in mixed moist tropical forests with special reference to Asia: lessons learned and myths perpetuated. J Forest 97:14–19

Ashton MS, Gunatilleke CVS, Singhakumara BMP, Gunatilleke I (2001a) Restoration pathways for rain forest in southwest Sri Lanka: a review of concepts and models. For Ecol Manage 154:409–430

Ashton MS, Mendelsohn R, Singhakumara BMP, Gunatilleke CVS, Gunatilleke I, Evans A (2001b) A financial analysis of rain forest silviculture in southwestern Sri Lanka. For Ecol Manage 154:431–441

Asikainen A, Björheden R, Nousiainen I (2002) Cost of wood energy. In: Richardson J, Björheden R, Hakkila P, Lowe AT, Smith CT (eds) Bioenergy from sustainable forestry guiding principles and practice, vol 71. Kluwer, Dordrecht, pp 125–157

Aus Frederiksen: Borchert (488), Putz (792), Sist (859)

Barreto P, Amaral P, Vidal E, Uhl C (1998) Costs and benefits of forest management for timber production in eastern Amazonia. For Ecol Manage 108:9–26

Barik SK, Pandey HN, Tripathi RS, Rao P (1992) Microenvironment variability and species diversity in treefall gaps in a sub-tropical broadleaved forest. Vegetatio 103:31–40

Baskent EZ, Keles S (2005) Spatial forest planning: a review. Ecol Modell 188(2–4):145–173

Battaglia M, Sands P, White D, Mummery D (2004) CABALA: a linked carbon, water and nitrogen model of forest growth for silvicultural decision support. For Ecol Manage 193:251–282

Bawa KS, Seidler R (1998) Natural forest management and conservation of biodiversity in tropical forests. Conserv Biol 12(1):46–55

Bertault JG, Dupuy B, Maître HF (1995) Silviculture for sustainable management of tropical moist forest. Unasylva 46(181):3–9

Bhattacharya P, Prasad R, Bhattacharyya R, Asokan A (2008) Towards certification of wild medicinal and aromatic plants in four Indian states. Unasylva 230(59):35–44

Boot RGA, Gullison RE (1995) Approaches to developing sustainable extraction systems for tropical forest products. Ecol Appl 5(4):896–903

Boy J, Wilcke W (2008) Tropical Andean forest derives calcium and magnesium from Saharan dust. Glob Biogeochem Cycles 22, GB1027. doi:10.1029/2007GB002960

Boy J, Rollenbeck R, Valarezo C, Wilcke W (2008) Amazonian biomass burning-derived acid and nutrient deposition in the north Andean montane forest of Ecuador. Glob Biogeochem Cycles 22, GB4011. doi:10.1029/2007GB003158

Brokaw NVL (1985) Gap-phase regeneration in a tropical forest. Ecology 66:682–687

Brokaw NVL (1987) Gap-phase regeneration of three pioneer tree species in a tropical forest. J Ecol 75:9–19

Bruenig EF (1996) Conservation and management of tropical rainforests: an integrated approach to sustainability. CAB International, Wallingford

Bruenig EF, Poker J (1989) Management of tropical rainforests – Utopia or chance of survival? Proceedings of an international symposium at the Food and Agriculture Development Centre

of the German Foundation for International Development (DSE) in Feldafing, 15–21 Jan 1989. Nomos Verlagsgesellschaft, Baden-Baden

Campos JJ, Finegan B, Villalobos R (2001) Management of goods and services from neotropical forest biodiversity: diversified forest management in Mesoamerica. Assessment, conservation and sustainable use of forest biodiversity. CBD Technical Series No. 3 (cbd-ts03), pp 5–16

CBD (1992) Convention on biological diversity. http://www.cbd.int/

CBD (2004) Addis Ababa principles and guidelines for the sustainable use of biodiversity (CBD guidelines). Secretariat of the Convention on Biological Diversity, Montreal

Cid-Liccardi CD, Kramer T (2009) Managing carbon sequestration in tropical forests. In: Tyrrell ML, Ashton MS, Spalding D, Gentry B (eds) Forests and carbon: a synthesis of science, management, and policy for carbon sequestration in forests. Report Number 23, Yale F&ES Publication Series, New Haven, CT, pp 255–279

Clark DA, Clark DB (1999) Assessing the growth of tropical rain forest trees: issues for forest modeling and management. Ecol Appl 9(3):981–997

Coates KD, Burton PJ (1997) A gap-based approach for development of silvicultural systems to address ecosystem management objectives. For Ecol Manage 99:337–354

Crome FHJ, Richards GC (1988) Bats and gaps: microchiropteran community structure in a Queensland rain forest. Ecology 69:1960–1969

Dawkins HC, Philips MS (1998) Tropical moist forest silviculture and management: a history of success and failure. CAB International, Wallingford

de Graaf NR, Poels RLH, Van Rompaey RSAR (1999) Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. For Ecol Manage 124:123–135

De Haan JAK (2008) What is needed to improve tropical conservation? Appropriate education, training, and encouragement. Environmentalist 28:171–173

Denslow JS, Schulz JC, Vitousek PM, Strain BR (1990) Growth responses of tropical shrubs to treefall gap environments. Ecology 71:165–179

Dirzo R, Horvitz CC, Quevedo H, Lopéz, MA (1992) The effect of gap size and age on the understory herb community of a tropical Mexican rain forest. J Ecol 80:809–822

Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J (1994) Carbon pools and flux of global forest ecosystems. Science 263:185–191

Dykstra D, Heinrich R (1996) FAO model code of forest harvesting practice. FAO, Rome, 85 pp

Enters T, Durst PB, Applegate GB, Kho PCS, Man G (eds) (2002) Applying reduced impact logging to advance sustainable forest management. Conference Proceedings, Kuching, 26 Feb to 1 Mar 2001. Regional Office for Asia and the Pacific, FAO, Bangkok

Fabian P, Kohlpaintner M, Rollenbeck R (2005) Biomass burning in the Amazon – fertilizer for the mountaineous rain forest in Educador. ESPR – Environ Sci Pollut Res 12:290–296

FAO (2009) The state of food insecurity in the world. FAO, Rome

FAO (2010) Global forest resources assessment 2010 – key findings. FAO, Rome. http://www.fao.org/forestry/fra2010

FAO/UNECE (2006) Forest products annual market review, 2005–2006. Geneva Timber and Forest Study Paper 21. UN, New York

Farnham P (2001) Precision forestry: finding the context. In: Briggs D (ed) Precision forestry. Proceedings of the 1st international precision forestry cooperative symposium. University of Washington, College of Forest Resources, University of Washington College of Engineering, USDA Forest Service, Seattle, pp 3–5

Feldpausch TR, Jirka S, Passos CAM, Jaspar F, Rhia S (2005) When big trees fall: damage and carbon export by reduced impact logging in southern Amazonia. For Ecol Manage 219:199–215

Finkeldey R, Ziehe M (2004) Genetic implications of silvicultural regimes. For Ecol Manage 197:231–244

FORSYS (2010) COST Action FP0804 – Forest Management Decision Support Systems (FORSYS). http://fp0804.emu.ee/wiki/index.php/Category:Decision_support_system.access. Accessed 7 Jul 2010

García-Fernández C, Ruiz Pérez M, Wunder S (2008) Is multiple-use forest management widely implementable in the tropics? For Ecol Manage 256:1468–1476

Glück P (1987) Social values in forestry. Ambio 16(2-3):158–160

Godoy R, Lubowski R, Markandya A (1993) A method for the economic valuation of non-timber tropical forest products. Econ Bot 47(3):220–233

Grainger A (1990) Modelling the impact of alternative afforestation strategies to reduce carbon emissions. In: Proceedings of the intergovernmental panel on climate change (IPCC) conference on tropical forestry response options to global climate change, Sao Paulo, 9–12 Jan 1990. Report No. 20P-2003. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, pp 93–104

Guariguata MR, Cornelius JP, Locatelli B, Forner C, Sánchez-Azofeifa GA (2008) Mitigation needs adaptation: tropical forestry and climate change. Mitig Adapt Strateg Glob Change 13:793–808

Guariguata MR, García-Fernández C, Sheil D, Nasi R, Herrero-Jáuregui C, Cronkleton P, Ingram V (2010) Compatibility of timber and non-timber forest product management in natural tropical forests: perspectives, challenges, and opportunities. For Ecol Manage 259:237–245

Günter S, Cabrera O, Weber M, Stimm B, Zimmermann M, Fiedler K, Knuth J, Boy J, Wilcke W, Lost S, Makeschin F, Werner F, Gradstein R, Mosandl R (2008) Natural forest management in neotropical mountain rain forests – an ecological experiment. In: Beck E et al (eds) Gradients in a tropical mountain ecosystem of Ecuador, vol 198, Ecological studies. Springer, Berlin, pp 347–359

Hall P, Bawa K (1993) Methods to assess the impact of extraction of non-timber tropical forest products on plant populations. Econ Bot 47:234–247

Harrison S (1987) Treefall gaps versus forest understory as environments for a defoliating moth on a tropical shrub. Oecologia 73:65–68

Hiremath AJ (2004) The ecological consequences of managing forests for non-timber products. Conserv Soc 2(2):211–216

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setala H, Symstad AJ, Vandermeer J, Wardle DA (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge and needs for future research. Ecol Monogr 75:3–36

Huth A, Ditzer T (2000) Simulation of the growth of a dipterocarp lowland rain forest with FORMIX3. Ecol Modell 134:1–25

Huth A, Ditzer T (2001) Long-term impacts of logging in a tropical rain forest: a simulation study. For Ecol Manage 142:35–51

Hwan Ok Ma (2007) Challenges for sustainable tropical timber industry: utilization of wood residues and waste. In: Bioenergy from sustainable forestry: guiding principles and practice. Presentation at the international conference on wood-based bioenergy, Hannover, 17–19 May 2007

Iliadis LS (2005) A decision support system applying an integrated fuzzy model for long-term forest fire risk estimation. Environ Modell Softw 20:613–621

IPCC (Intergovernmental Panel on Climate Change) (2003) Definitions and methodological options to inventory emissions from direct human-induced degradation of forests and devegetation of other vegetation types. Institute for Global Environmental Strategies (IGES), Hayama

IPCC (Intergovernmental Panel on Climate Change) (2007a) Climate change 2007, Summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge

IPPC (Intergovernmental Panel on Climate Change) (2007b) Technical summary. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge

ITTO (2006) Status of tropical forest management 2005. International Tropical Timber Organisation Technical Series No 24. ITTO, Yokohama

ITTO, IUCN (2009) ITTO/IUCN guidelines for the conservation and sustainable use of biodiversity in tropical timber production forests. ITTO Policy Development Series No 17. ITTO, Yokohama

Johns AD (1992) Vertebrate responses to selective logging: implications for the design of logging systems. Philos Trans R Soc Lond B 335:437–442

Kammesheidt L, Köhler P, Huth A (2002) Simulating logging scenarios in secondary forest embedded in a fragmented neotropical landscape. For Ecol Manage 170:89–105

Keller M, Asner GP, Blate G, McGlocklin J, Merry F, Pena-Claros M, Zweede J (2007) Timber production in selectively logged tropical forests in South America. Front Ecol Environ 5:213–216

Knoke T, Aguirre N, Stimm B, Weber M, Mosandl R (2009) Can tropical farmers reconcile subsistence demands with forest conservation? Front Ecol Environ 7(10):548–554

Kobayashi S (1994) Effects of harvesting impacts and rehabilitation of tropical rain forest. J Plant Res 107:99–106

Kuptz D, Grams T, Günter S (2010) Light acclimation of four native tree species in felling gaps within a tropical mountain rain forest. Trees Struct Funct 24(1):117–127. doi:10.1007/s00468-009-0385-1

Lambert F (1992) The consequences of selective logging for Bornean lowland forest birds. Philos Trans R Soc Lond B 335:443–457

Lamprecht H (1986) Waldbau in den Tropen. Parey, Hamburg

Laurance WF (2008) Changing realities for tropical forest managers. ITTO Trop For Update 18 (4):6–8

Lawrence A (2003) No forest without timber? Int Forest Rev 5:87–96

Lawton RO, Putz FE (1988) Natural disturbance and gap-phase regeneration in a wind-exposed tropical cloud forest. Ecology 69:764–777

Levey OJ (1988) Tropical wet forest treefall gaps and distribution of understory birds and plants. Ecology 69:1076–1089

Mäkelä A, Landsberg J, Ek AR, Burk TE, Ter-Mikaelian M, Ågren GI, Oliver CD, Puttonen P (2000) Process-based models for forest ecosystem management: current state of the art and challenges for practical implementation. Tree Physiol 20:289–298

Mead DJ (2001) Plantation silviculture and bioenergy production. In: Richardson J, Bjorheden R, Hakkila P, Lowe AT, Smith CT (eds) Bioenergy from sustainable forestry: principles and practice. Forest Research Bulletin 223. New Zealand Forest Research Institute, Rotorua, pp 6–16.

Mead DJ (2005) Forests for energy and the role of planted trees. Crit Rev Plant Sci 24(5):407–421

Meister K, Ashton MS (2009) Carbon dynamics of tropical forests. In: Tyrrell ML, Ashton MS, Spalding D, Gentry B (eds) Forests and carbon – a synthesis of science, management, and policy for carbon sequestration in forests. Report Number 23, Yale F&ES Publication Series, New Haven, pp 73–106

Michon G, De Foresta H, Levang P, Verdeaux F (2007) Domestic forests: a new paradigm for integrating local communities' forestry into tropical forest science. Ecol Soc 12(2). http://www.ecologyandsociety.org/vol12/iss2/art1/

Miehle P, Grote R, Battaglia M, Feikema PM, Arndt SK (2010) Evaluation of a process-based ecosystem model for long-term biomass and stand development of *Eucalyptus globulus* plantations. Eur J For Res 129:377–391

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: biodiversity synthesis. World Resources Institute, Washington

Moura-Costa P (1996) Tropical forestry practices for carbon sequestration. In: Schulte A, Schöne D (eds) Dipterocarp forest ecosystems. World Scientific, Singapore, p 334

Nabuurs GJ, Mohren GMJ (1993) Carbon fixation through forestation activities. IBN Research Report 93/4. Institute for Forestry and Nature Research, Wageningen

Nair PKR (1993) An introduction to agroforestry. Kluwer, Dordrecht

National Academy of Sciences (1980) Firewood crops: shrub and tree species for energy production, vol 1. National Academy Press, Washington

Nightingale JM, Phinn SR, Held AA (2004) Ecosystem process models at multiple scales for mapping tropical forest productivity. Prog Phys Geogr 28(2):241–281

Öhman K (2001) Forest planning with consideration to spatial relationships. Doctoral thesis, Swedish University of Agricultural Sciences, Umea. Acta Universitatis Agriculturae Sueciae Silvestria 198

Olegário J, de Carvalho P, Macedo JN, Pokorny B, Sabogal C, Zweede J (2008) Systems for SFM. ITTO Trop For Update 18(4):9–11

Ong RC, Kleine M (1996) DIPSIM: dipterocarp forest growth simulation model, a tool for forest-level management planning. In: Schulte A, Schöne D (eds) Dipterocarp forest ecosystems. World Scientific, Singapore, pp 228–245

Panayotou T, Ashton PS (1993) Not by timber alone: economics and ecology for sustaining tropical forests. Island, Washington

Pariona W, Fredericksen TS, Licona JC (2003) Natural regeneration and liberation of timber species in logging gaps in two Bolivian tropical forests. For Ecol Manage 181:313–322

Pears D, Putz FE, Vanclay JK (2003) Sustainable forestry in the tropics: panacea or folly? For Ecol Manage 172:229–247

Peña-Claros M, Peters EM, Justiniano MJ, Bongers F, Blate GM, Fredericksen TS, Putz FE (2008a) Regeneration of commercial tree species following silvicultural treatments in a moist tropical forest. For Ecol Manage 255:1283–1293

Peña-Claros M, Fredericksen TS, Alarcón A, Blate GM, Choque U, Leaño C, Licona JC, Mostacedo B, Pariona W, Villegas Z, Putz FE (2008b) Beyond reduced-impact logging: silvicultural treatments to increase growth rates of tropical trees. For Ecol Manage 256:1458–1467

Peng C (2000) Growth and yield models for uneven-aged stands: past, present and future. For Ecol Manage 132:259–279

Peters CM, Gentry AH, Mendelsohn RO (1989) Valuation of an Amazonian rainforest. Nature 339:655–656

Phillips OL, Malhi Y, Higuchi N, Laurance WF, Percy V, Núñez PV, Vásquez RM, Laurance SG, Ferreira LV, Stern M, Brown S, Grace J (1998) Changes in the carbon balance of tropical forests: evidence from long-term plots. Science 282:439–442

Pinard MA, Putz FE (1996) Retaining forest biomass by reducing logging damage. Biotropica 28:278–295

Pirard R, Karsenty A (2009) Climate change mitigation: should “avoided deforestation” be rewarded? J Sustain Forest 28:434–455

Poore D, Burgess P, Palmer J, Rietbergen S, Synnott T (1989) No timber without trees: sustainability in the tropical forest. A study for International Timber Organization. Earthscan, London

PRB (Population Reference Bureau) (2009) World population data sheet. http://www.prb.org/pdf09/09wpds_eng.pdf. Accessed 8 Jul 2010

Putz FE (1983) Treefall pits and mounds, buried seeds, and the importance of soil disturbance to pioneer trees on Barro Colorado Island. Panama. Ecology 64:1069–1074

Putz FE, Pinard MA (1993) Reduced-impact logging as a carbon-offset method. Conserv Biol 7:755–757

Putz FE, Redford KH, Fimbel R, Robinson JG, Blate GM (2000) Biodiversity conservation in the context of tropical forest management. Biodiversity series, impact studies, vol 1. Environment paper 75. World Bank, Washington

Putz FE, Blate GM, Redford KH, Fimbel R, Robinson JG, Fimbel R (2001) Tropical forest management and conservation of biodiversity: an overview. Conserv Biol 15:7–20

Putz FE, Zuidema PA, Pinard MA, Boot RGA, Sayer JA, Sheil D, Sist P, Elias VJK (2008) Improved tropical forest management for carbon retention. PLoS Biol 6:1368–1369. doi:10.1371/journal.pbio.0060166

Salati E, Nobre CA (1991) Possible climatic impacts of tropical deforestation. Clim Change 19:177–196

Sanford RL Jr (1989) Fine root biomass under a tropical forest light gap opening in Costa Rica. J Trop Ecol 5:251–256

Sanford RL Jr (1990) Fine root biomass underforest light gap openings in an Amazon rain forest. Oecologia 83:541–545
Schelhaas MJ, van Esch PW, Groen TA, de Jong BHJ, Kanninen M, Liski J, Masera O, Mohren GMJ, Nabuurs GJ, Palosuo T, Pedroni L, Vallejo A, Vilén T (2004) CO2FIX V 3.1 – a modelling framework for quantifying carbon sequestration in forest ecosystems. Alterra-rapport 1068. Alterra, Wageningen
Schemske OW, Brokaw N (1981) Treefall and distribution of understory birds in a tropical forest. Ecology 62:938–945
Schulze M (2008) Technical and financial analysis of enrichment planting in logging gaps as a potential component of forest management in the eastern Amazon. For Ecol Manage 255:866–879
Shelly TE (1988) Relative abundance of day-flying insects in treefall gaps vs. shaded understory in a Neotropical forest. Biotropica 20:114–119
Siry JP, Cubbage FW, Ahmed MR (2005) Sustainable forest management: global trends and opportunities. For Policy Econ 7:551–561
Sist P, Sheil D, Kartawinata K, Priyadi H (2003) Reduced-impact logging in Indonesian Borneo: some results confirming the need for new silvicultural prescriptions. For Ecol Manage 179:415–427
Smith J, Applegate G (2004) Could payments for forest carbon contribute to improved tropical forest management? For Policy Econ 6:153–167
Smith DM, Larson BC, Kelty MJ, Ashton PMS (1997) The practice of silviculture: applied forest ecology, 9th edn. Wiley, New York
Sun D-Z, Zhang T, Shin S-I (2004) The effect of subtropical cooling on the amplitude of ENSO: a numerical study. J Clim 17:3786–3798
Ticktin T (2004) The ecological implications of harvesting non-timber forest products. J Appl Ecol 41:11–21
Tobias D, Mendelsohn R (1991) Valuing ecotourism in a tropical rain-forest reserve. Ambio 20 (2):91–93
Uhl C, Clark K, Maquimo P (1988) Vegetation dynamics in Amazonian treefall gaps. Ecology 69:751–763
UN (1992a) Agenda 21. http://www.un.org/esa/dsd/agenda21/
UN (1992b) Non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests. http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm
UNFCCC (1992) United Nations framework convention on climate change. http://unfccc.int
Van Bodegom AJ, Savenije H, Wit M (eds) (2009) Forests and climate change: adaptation and mitigation. Tropenbos International, Wageningen
Van Noordwijk M, Tomich TP, Verbist B (2001) Negotiation support models for integrated natural resource management in tropical forest margins. Conserv Ecol 5(2):21. http://www.consecol.org/vol5/iss2/art21/
Vanclay JK (1994) Modelling forest growth and yield applications to mixed tropical forests. CAB International, Wallingford
Vanclay JK (1995) Growth models for tropical forests: a synthesis of models and methods. For Sci 41(1):7–42
Vitousek PM, Denslow JS (1986) Nitrogen and phosphorus availability in treefall gaps of lowland tropical rainforests. J Ecol 74:1167–1178
Wadsworth FH, Zweede JC (2006) Liberation: acceptable production of tropical forest timber. For Ecol Manage 233:45–51
Walters BB, Sabogal C, Snook LK, de Almeida E (2005) Constraints and opportunities for better silvicultural practice in tropical forestry: an interdisciplinary approach. For Ecol Manage 209:3–18
Wang S, Wilson B (2007) Pluralism in the economics of sustainable forest management. For Policy Econ 9:743–750

Watson RT, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (eds) (2000) Land use, land-use change, and forestry. A special report of IPCC. Cambridge University Press, Cambrisge

Weber M, Günter S, Aguirre N, Stimm B, Mosandl R (2008) Reforestation of abandoned pastures: silvicultural means to accelerate forest recovery and biodiversity. In: Beck E et al (eds) Gradients in a tropical mountain ecosystem of Ecuador, vol 198, Ecological studies. Springer, Berlin, pp 431–441

Whitmore TC (1990) An introduction to tropical rain forest. Clarendon, Oxford

Whyte G (1996) Multi-criteria planning and management of forest sustainability. In: Schulte A, Schöne D (eds) Dipterocarp forest ecosystems. World Scientific, Singapore, pp 189–205

Wilcke W, Günter S, Alt F, Geißler Ch, Boy J, Knuth J, Oelmann Y, Weber M, Valarezo C, Mosandl R (2009) Response of water and nutrient fluxes to improvement fellings in a tropical montane forest in Ecuador. For Ecol Manage 257:1292–1304

Wunder S (1999) Promoting forest conservation through ecotourism income? CIFOR Occasional Paper No. 21. CIFOR, Bogor

Zarin DJ, Schulze MD, Vidal E, Lentini M (2007) Beyond reaping the first harvest: management objectives for timber production in the Brazilian Amazon. Conserv Biol 21:916–925